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A Novel Memory-based ARQ System with its Analysis of Throughput

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Abstract

The Primitive Bit Error Rate is much higher in severe electronic-magnetic environment, which results in much more retransmissions for an ARQ data transceiver; this means a lower efficiency of transmission. To cope with the above problem, this paper proposes a new mechanism, which is based on majority-voting. Through theoretical analysis and simulations, this novel approach shows better performance than those conventional ones.

Keywords: Automatic Repeat reQuest, Bit Error Rate, Majority Voting.

1. Introduction

For high reliability of data transmission, ARQ is a conventional method. For many years, the throughput efficiency, which the conventional ARQ method can reach, has been analyzed in theory [1-8]. Almost each analysis is done at those good channels, i.e. the primitive BER is below 1E-3, while those severe channels (for those systems with BER beyond 1E-2) are seldom considered. Under such a severe circumstance, the theoretical analysis is not suitable for a technician to adjust his design or scheme. In this paper, it tries to simplify the analysis and derivation, and provide theoretical aids to those designs of communication system with ARQ. In part 2, some generalized close forms of certain ARQ systems are given with some useful conclusions. In part 3, the new approach of ARQ is described in detail with its performance. And in the final part, the conclusion is present.

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2. Analysis for the Conventional ARQ Schemes

There are three major conventional scheme of ARQ, which are Stop-Wait (SW), Go-Back-N and Selective Repeat (SR). In the half-duplex communications systems, SW-ARQ and SR-ARQ are preferred. SW-ARQ is the simplest one among all the ARQ schemes; while the SR-ARQ is more complicated. Go-Back-N is generally used in synchronous duplex system; hence, it will not be discussed in the following.

For convenience of analysis, some denotations should be given in advance. P_x: the primitive bit error rate, which represents the remaining errors in the receiver before error checking of ARQ; ρ: ratio of frame length between forward and backward channel in a single frame; L: number of bits in the forward frame.

Some assumptions are: Firstly, Error probability transition model of channel is Binary-Symmetrical-Channel, i.e. BSC. Secondly, Error events are random processes, each of which has the identical independent distribution. Thirdly, BER of the backward channel is almost 0. This condition must be met and is easily met. In general, BER of the backward channel is much lower than that of forward channel. Under such circumstance, computation can be simplified, while the precision of calculation is kept well, without having too much influence on the computation on the whole.

2.1. Analysis of SW-ARQ

The basic performance is given to deal with the SW-ARQ. For a data frame at length of L-bits, the correct probability at one time is

$$P_1 = (1-P_x)^L \tag{1}$$

While the ARQ ends at the N-th transmission with a probability

$$P_N = (1-P_x)^L \cdot \left(1-(1-P_x)^L\right)^{N-1} \tag{2}$$

This means the probability of the ARQ event finished-sequence is subject to geometric-distribution. From (2), it is obvious that the success probability is very low when the primitive BER is larger than 0.01.

Combine (1) and (2), the average length of the SW-ARQ is given as follows,

$$\overline{L} = L \times \sum_{i=1}^{\infty} i \times P_i = L \times (1-P_X)^L \sum_{i=1}^{\infty} i \times \left(1-(1-P_X)^L\right)^{i-1} = \frac{L}{(1-P_X)^L} \tag{3}$$

Derived from (3), the theoretical efficiency of SW-ARQ is

$$\eta = \frac{L}{\overline{L}} = (1-P_X)^L \tag{4}$$

Considering the duration occupied by the backward channel, the average efficiency of SW-ARQ is

$$\eta_p = (1-\rho) \times \eta \times \frac{L-L_{CRC}}{L} \tag{5}$$

where η_p is the practical average efficiency, L_{CRC} is the bits length of the checksum for CRC (cyclic redundant checking). CRC is the most common-used method for error checking.

2.2. Analysis of SR-ARQ Scheme

Let's take a further view into the SR-ARQ scheme. For a SR-ARQ, it divides a large frame into some smaller sub-frames. For a forward transmission, only those erroneous sub-frames need retransmission, so as to avoid too many transitions from sending to receiving, thus achieves a quite higher efficiency.

Assume that the maximum number of the sub-frames is K, each of the sub-frames is at a length of L bits, and the event of the error bits is subject to an identical independent distribution. Thus, it is known that success probability for each sub-frame is subject to the geometric distribution. Denotes the error probability of one-direction transmission as P_y, so it is obtained

$$P_y = 1 - \left(1 - P_X\right)^{L_s} \tag{6}$$

where L_s is the bits length of the sub-frame.

As for all the K sub-frames, it has a success probability of transmission at the first transmission, so it is obtained

$$P_1 = \left(1 - P_y\right)^K \tag{7}$$

For the second time of the transmission of the K sub-frames, it ends up with the correct probability as follows

$$P_2 = \left(1 - P_y\right)^K \left[\left(1 + P_y\right)^K - 1\right] \tag{8}$$

It can be shown in mathematical induction. All the K sub-frames are transmitted successfully at the I-th time, it has a probability of

$$P_I = \begin{cases} \left(1 - P_y\right)^K, & I = 1; \\ \left(1 - P_y\right)^K \left[\left(\sum_{i=0}^{I-1} P_y^i\right)^K - \left(\sum_{i=0}^{I-2} P_y^i\right)^K\right], & I \geq 2 \end{cases} \tag{9}$$

Equation (9) gives the probability density function of the success sequence for the SR-ARQ. It is useful for the designer to have a direct impression on the theoretical calculation. It is obvious that the average efficiency of SR-ARQ is not high as expected, especially when the primitive BER is high.

Equation (9) is too general to apply to computing the efficiency. From it, for success of transmission at the I-th retransmission, how many and which of the sub-frames is asked to be retransmitted is still unknown. However, (9) can be used to calculate the average efficiency, listed in (10),

$$\left(1 - P_y\right)^K + \sum_{I=2}^{\infty} I \cdot \left(1 - P_y\right)^K \left[\left(\sum_{i=0}^{I-1} P_y^i\right)^K - \left(\sum_{i=0}^{I-2} P_y^i\right)^K\right] = \left(1 - P_y\right)^K - \sum_{n=0}^{K} \binom{K}{n} (-1)^n \frac{P_y^n - 2}{P_y^n - 1} \tag{10}$$

3. An Improved Method and Its Performance

3.1. Derivation of the Algorithm

In theory, SR-ARQ can not reach a high efficiency as expected; however, each transition from receiving to sending or vice versa needs extra time in a practical data transmission system. For a half-duplex system, such transition is so frequent that the reliability of the system would fall at an unexpected speed; hence, SR-ARQ scheme lowers the total transmission time and provides better protection for the communication system. Thus, many methods [4-8] have been proposed. By combining the error detection mechanism with the FEC (forward error correction), those bits or sub-frames being retransmitted are coded to form a new codeword, which will be decoded when the entire codeword is received. This method can reach a higher efficiency, however, it needs a robust synchronization; on the other hand, when the primitive BER is high, it is easy to exceed the correction capability of the code. To avoid the difficulty of the strict synchronization, we suggest a new mechanism based on the majority voting, where no extra coding is needed. It carries out as follows

- a. At the transmit end, if it receives a error indication in the backward channel, it retransmits the frame in its original form;
- b. At the receiver end, does the parity checking. If it is correct, the procedure ends.
- c. If errors are found during the parity checking, the received frames are stored into the correspondent buffer and queued according the inputting order.
- d. At the odd time of reception of the retransmission, do the majority voting and forms a new form of the received frames.
- e. Check the parity of the new frame. If there is no error, the transmission ends; otherwise, returns to a.

This kind of ARQ based on the majority voting needs no strict synchronization; and even though some missing frames take place, it would have no effect on the majority voting.

3.2. Performance Analysis

For the ARQ based on the majority voting, the point is to get its remaining bit error rate (RBER). Generally, in BSC, such RBER takes form of this

$$P_e = \sum_{i=0}^{C_e} \binom{M}{i} P_X^i \cdot (1-P_X)^{M-i} \tag{11}$$

where P_e is the remaining BER; M is the repeat count, it is often odd; C_e is the threshold, take a value of $\lceil \frac{M}{2} \rceil$ ($\lceil . \rceil$ denotes the ceiling operation for getting an integer).

From (11), Table 1 can be obtained.

Table 1 RBER of majority voting

P_x	0.1	0.01	0.005	0.001
2 in 3	0.028	0.0002920698	0.000074	2.992E-6
3 in 5	0.00856	0.0000098506	0.00000124	9.985E－9
4 in 7	0.002728	3.4167E-7	2.1614E-8	3.492E－11

From table 1, it is obvious that RBER falls rapidly with the increase number of the frames participating in the majority voting.

In order to obtain the average length of the majority voting ARQ, such a method is used. Firstly, divide time of the retransmission into tow groups such as the odd one and the even one, and calculate the correct retransmission probability respectively. Secondly, compute the average time of retransmission. Thirdly, the average time of the retransmission, average length are obtained, so the average efficiency is reached.

In theory, the average length is written in the following

$$\overline{L} = L \times \left(\sum_{i=1}^{\infty} 2i \times P_i + \sum_{i=2}^{\infty} (2i-1) \times P_e \right) = L \times \left((1-P_X)^L \, 2\sum_{i=1}^{\infty} i \times \left(1-(1-P_X)^L\right)^{i-1} + \sum_{i=2}^{\infty} (2i-1) \times \sum_{n=0}^{i} \binom{2i}{n} P_X^n \times (1-P_X)^{2i-n} \right) \tag{12}$$

It is very difficult to simplify (12) so as to get a close-formed expression. However, we can simplify our calculation along this way by partial calculation. Firstly, we calculate the RBER according to (11). Secondly, compute the average length from (4) and (5). Finally, compute the overall efficiency. For a real system, it is important to know how many memory buffer blocks should be allocated.

Table 2. pdf simulation for the ARQ based on majority voting (MV)

BER / MV time location	P_x=10^{-1}	P_x=10^{-2}	P_x=10^{-3}	P_x=10^{-4}	BER / MV time location	P_x=10^{-1}	P_x=10^{-2}	P_x=10^{-3}	P_x=10^{-4}
1	0.00000	0.00000	0.00000	0.17333	13	0.32256	0	0	0
2	0.00000	0.00000	0.02384	0.78222	15	0.39179	0	0	0
3	0.00000	0.00974	0.96485	0.04444	17	0.17538	0	0	0
4	0.00000	0.00410	0.00848	0	19	0.05487	0	0	0
5	0.00000	0.88359	0.00283	0	21	0.01590	0	0	0
6	0.00000	0.00718	0	0	23	0.00513	0	0	0
7	0.00000	0.09282	0	0	25	0.00154	0	0	0
9	0.00000	0.00256	0	0	27	0.00000	0	0	0
11	0.03231	0	0	0	29	0.00051	0	0	0

According to the above simplified computation, the reciprocal of the overall efficiency is the average amount of the memory buffer blocks. We can choose a suitable number of the buffer blocks by simulation (Table 2 is a simulation results).

From table 3, it manifests MV-ARQ is much more robust than those of simple form of ARQ. Even though the primitive BER is at 0.1, the MV-ARQ only needs no more than 21 blocks of memory buffer; when the primitive BER is below 0.01, the transmission finishes within 5 times of retransmission at a probability of 90%. So MV-ARQ is by far more advantageous than SW-ARQ and SR-ARQ as well.

4. Conclusions

It is important to improve the efficiency of the ARQ mechanism in a severe electronic-magnetic environment. By allocating some multi-degrees of memory buffer block, and taking the original format of the data frames, the MV-ARQ shows a good performance. MV-ARQ is a kind of time diversity, thus acquires a diversity gain. Nowadays, it is very cheap to implement a large scale of memory chips, so that it will not add too heavy burden to a real system. Therefore, MV-ARQ is very practical.

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